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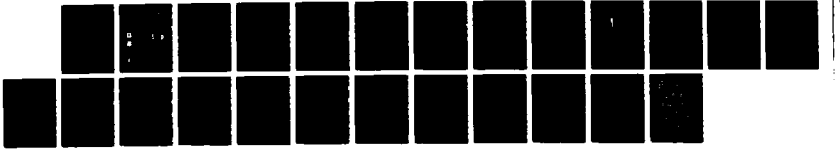

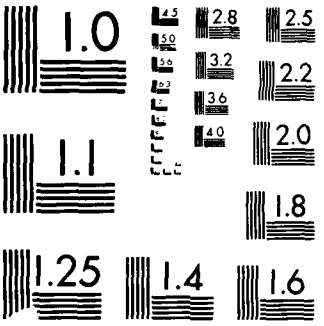

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Capabilities and Limitations of Estimating Cloud Amount From the Special Sensor Microwave/Imager (SSM/I)

GERALD W. FELDE

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A new operational sensor will be on board the next polar-orbiting Defense Meteorological Satellite Program spacecraft, which is scheduled to be launched in June 1987. It is called the Special Sensor Microwave/Imager (SSM/I). The SSM/I is a seven channel, four frequency, linearly polarized, passive microwave radiometer. The SSM/I will provide estimates of several surface and atmospheric parameters. One of the parameters is cloud amount (percent cloud coverage), which is the topic of this report. SSM/I cloud amount estimates will include some of the situations in which there are difficulties with the Air Force Global Weather Central's Real-Time Nephanalysis automated global cloud analysis using visible and infrared satellite data. Hughes Aircraft Company developed two algorithms for estimating cloud amounts from SSM/I brightness temperatures. One is applicable over snow backgrounds; the other, over land backgrounds. However, it is not possible to obtain cloud amount estimates for land covered with vegetation. No cloud amount estimation algorithms for ocean or oceanic ice backgrounds were required (cont.)

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to be developed; even though the potential over both of these backgrounds is good.

The accuracy of the SSM/I cloud amount estimates over snow and land backgrounds is expected to be good. The rms error of the estimated percent cloud amount is 3.2 percent for snow backgrounds and 7.8 percent for land backgrounds. However, the algorithms and error analyses were based entirely on simulated data which may not represent the variability of real data. Thus, the accuracy of the SSM/I cloud amount estimates quite possibly will not be as good as the calculated rms errors indicate. After the launch, SSM/I cloud amount estimates will be validated using interactively analyzed 1.5 nmi OLS visible and infrared data that will lead to cloud amounts considered to be the ground truth.

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Preface

The author thanks Dr. Richard C. Savage, Mark A. Zimmerman, and Lisa M. Neff of Hughes Aircraft Company for the development of the SSM/I cloud amount algorithms. I am particularly indebted to Dr. Savage for his helpful discussions on many aspects of the SSM/I. I would also like to acknowledge the useful suggestions received from Dr. Kenneth R. Hardy, Vincent J. Falcone, Jr., and James T. Bunting of AFGL/LYS.

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Capabilities and Limitations of Estimating Cloud Amount From the Special Sensor Microwave/Imager (SSM/I)

1. INTRODUCTION

Knowledge of clouds is important for the operation of Department of Defense airborne and spaceborne systems which are used for command, control, communications, transportation, and surveillance. A primary objective of the Defense Meteorological Satellite Program (DMSP) is to provide data to the Air Force Global Weather Central (AFGWC) to produce worldwide automated analyses of cloud amount, type, and altitude. The cloud analysis system is called the Real-Time Nephanalysis (RTNEPH) and is described by Fye.[1] RTNEPH's main source of data is the thermal infrared and visible imagery data from the DMSP Operational Linescan System (OLS) sensor, which flies on polar-orbiting satellites. The AFGWC uses the output of the RTNEPH in its global Numerical Weather Prediction (NWP) models.

The OLS visible and thermal infrared data impose some limitations on the automated RTNEPH cloud analysis scheme. The RTNEPH satellite data processor consists of two parts--one for visible data and one for infrared data. One obvious limitation of visible data is that it is only available at time when there is a suffi-

(Received for publication 15 April 1987)

1. Fye, F.K. (1978) The AFGWC Automated Cloud Analysis Model, AFGWC Technical Memorandum 78-002, AD A057176.

cient amount of reflected sunlight. In visible imagery, clouds are considerably brighter than most background surfaces and thus can be discerned. However, cloud interpretation is difficult over backgrounds with high or highly variable reflectivities such as snow cover, ice cover, deserts, and coastlines.

In thermal infrared imagery, generally clouds are colder than the background, and, the colder they are, the greater their height. Infrared cloud interpretation is difficult when the background temperatures are not accurately known, such as over areas lacking temperature measurements from surface stations and over land areas with rapid diurnal temperature changes. Underestimation of cloud amount or even nondetection of cloud occurs when the cloud-top temperature is higher than the background temperature. This situation happens most frequently with low-level temperature inversions when low stratus clouds are present, especially over snow, ice, or cold water backgrounds.

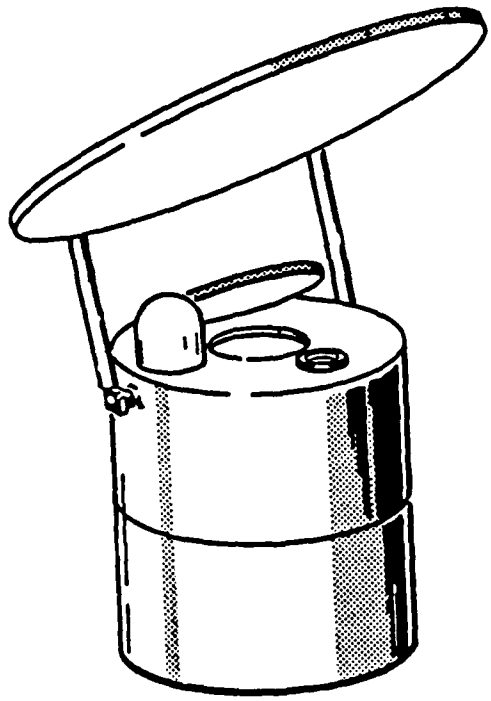
A new operational satellite sensor will provide estimates of cloud amount during some of the situations in which there are difficulties with the RTNEPH cloud analysis using only the visible and infrared data. It is a microwave sensor called the Special Sensor Microwave/Imager (SSM/I). The SSM/I will provide estimates of several other surface and atmospheric parameters in addition to cloud amount. Both the SSM/I and OLS will be on board the next DMSP spacecraft that is scheduled to be launched in June 1987. Estimation of cloud amount from SSM/I data is the topic of this report.

2. THE SSM/I

2.1 Instrument Description

The SSM/I is intended as an "all-weather" meteorological and oceanographic sensor and was developed by the Hughes Aircraft Company with support by the Air Force and Navy. It is a passive radiometer that measures energy emitted from the Earth/atmosphere system for seven microwave channels. Figure 1 shows the SSM/I radiometer and a list of its principal specifications. Each channel's frequency and polarization, scene station spacing, and effective field of view (FOV) is given in Table 1. There are four frequencies: 19, 22, 37, and 85 GHz, and two polarizations, vertical and horizontal, at each frequency except for the 22 GHz channel, which has only vertical polarization. The SSM/I measures emitted energy at intervals of 12.5 km at 85 GHz and 25 km at the three lower frequencies. The effective FOV decreases as the frequency increases and ranges from 55 km at 19 GHz down to 15 km at 85 GHz.

The SSM/I rotates in a circular scan with a period of 1.9 seconds, during which time the satellite advances 12.5 km. The details of its scan geometry are



WEIGHT	**90 lb**
SIZE	
• ANTENNA	24 × 26 in
• DRUM	14 in DIAMETER
	16 in HEIGHT
POWER	**45 W**
ORBIT	**833 km CIRCULAR**
	101 min PERIOD
	98.7° INCLINATION
	-SUN SYNCHRONOUS
SPACECRAFT	**DMSP BLOCK 5D-2**

Figure 1. SSM/I Radiometer Specifications

Table 1. SSM/I Channels and Resolution

Frequency (GHz) & Polarization (V = vertical, H = horizontal)	Scene Station Spacing (km)	Effective FOV (km)
19.35 V	25	55.3
19.35 H	25	55.1
22.2 V	25	48.6
37 V	25	32.2
37 H	25	32.7
85.5 V	12.5	14.8
85.5 H	12.5	14.8

shown in Figure 2. The angle between satellite nadir and the antenna beam is a constant 45°. Thus, as the antenna rotates, the beams define the surface of a cone and, from the orbital altitude of 833 km, make a constant zenith angle of 53.1°. Earth/atmosphere sensor data is collected over 102° of each rotation. This angle is centered on the satellite subtrack aft of the satellite and results in an Earth swath width of 1394 km. During the remaining 258° of each rotation, short bursts of calibration readings from hot and cold calibration sources are

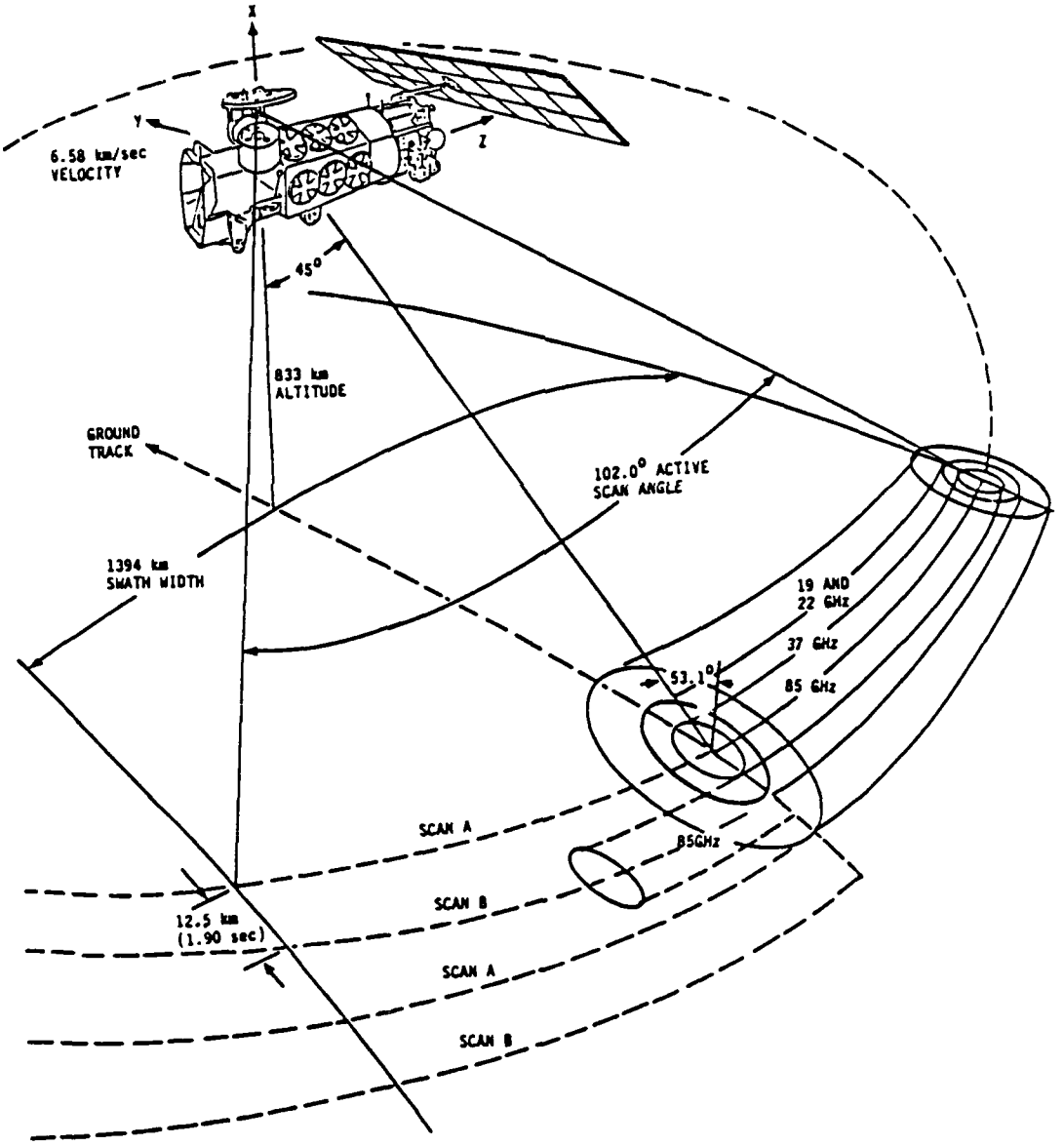


Figure 2. SSM/I Scan Geometry

taken. The radiometer outputs are sampled differently on alternate scans. Scans are labeled as "A" and "B." Each A scan contains 64 sets of concentric measurements by all seven channels and 64 sets of concentric measurements by the two 85 GHz channels taken midway between each of the all-frequency scene stations. Each B scan contains 128 sets of concentric measurements by the two 85 GHz channels. Further details of the SSM/I are given by Hollinger and Lo.[2]

2.2 Geophysical Parameter Retrieval

Relationships between the brightness temperature (the physical temperature a black body emitting the same intensity of radiation would have) observed from the various channels provide a means to determine several geophysical parameters. SSM/I software contains algorithms for estimating values for 11 different parameters listed in Table 2. The parameter extraction algorithms are discussed by the Hughes Aircraft Company.[3] This discussion also contains the actual com-

Table 2. Geophysical Parameters Estimated From SSM/I Data

(1) SW--Surface Wind Speed (Ocean)
(2) IC, IE, IA--Ice Concentration, Edge, Age (1st year or multiyear)
(3) RO, RL--Rain Rate (Ocean and Land)
(4) LWO, LWL--Liquid Water Content of Rain (Ocean and Land)
(5) CWO, CWL, CWI, CWS--Cloud Water Content (Ocean, Land, Ice, and Snow)
(6) WVO--Atmospheric Water Vapor Content (Ocean)
(7) SM--Soil Moisture (Land--Except Heavy Vegetation)
(8) SNW, SNE--Snow Water Content, Edge
(9) STL, STS--Surface Temperature (Land and Snow)
(10) CAL, CAS--Cloud Amount (Land and Snow)
(11) TYPE--Surface Characteristic [ocean, sea ice, coast, flooded land, vegetation, arable soil, desert, heavy rain, snow, frozen soil/wet snow (indistinguishable to SSM/I), and glacial]

2. Hollinger, J.P., and Lo, R.C. (1983) SSM/I Project Summary Report, Naval Research Laboratory Technical Memorandum Report 5055.

3. Hughes Aircraft Company (1986a) Special Sensor Microwave/Imager (SSM/I) Computer Program Product Specification (Specification for AFGWC), Vol. III Environmental Parameter Extraction Computer Program Component (SMIEPE), Contract F04701-84-C-0036.

puter code listings. All the algorithms for extracting environmental parameters, except for the ice parameters and the surface characteristic parameter, use the brightness temperatures as independent variables in linear regression equations. The regression coefficients are determined using climatology, geophysical models, radiative transfer models, and an inversion algorithm. The ice algorithm is developed directly from physical relationships rather than regression. (See Lo[4] and Hughes Aircraft Company[5] for more details on the extraction of environmental parameters.)

The TYPE parameter (Item 11 in Table 2) algorithm uses the surface characteristic data base that is part of the SSM/I software package. It is a fixed data base of approximately 10 km resolution that distinguishes between ocean, land, coast, permanent oceanic ice and possible ice, the Antarctic ice cap, and possible heavy vegetation. Locations coded as possible ice are determined to be TYPE parameter ice or ocean from the ice concentration calculation portion of the ice algorithm. Locations tagged as ocean, coast, permanent oceanic ice, or Antarctica are accepted to be so, since such things presumably do not change. The TYPE parameter for locations coded as land or possible heavy vegetation are determined from a decision tree of brightness temperature discriminators. The discriminators are based on numerical models, published literature, and observations of SMMR (Scanning Multichannel Microwave Radiometer) data.[5]

3. SSM/I CLOUD AMOUNT ESTIMATES

Hughes Aircraft Company developed two algorithms for estimating cloud amounts (percent cloud coverage) from SSM/I brightness temperatures. One is applicable over land backgrounds; the other, over snow backgrounds. A discussion of why clouds over these backgrounds will be discernible with the SSM/I follows. Also, the cloud amount over land (CAL) and cloud amount over snow (CAS) algorithms are discussed.

3.1 Cloud Detection

Radiation measured by the SSM/I (in either of two orthogonal polarizations) comes from three sources--atmospheric emission, surface emission, and atmospheric emission reflected from the surface. Energy from the latter two sources

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4. Lo, R.C. (1983) A Comprehensive Description of the Mission Sensor Microwave Imager (SSM/I) Environmental Parameter Extraction Algorithm, Naval Research Laboratory Technical Memorandum Report 5199.

5. Hughes Aircraft Company (1985) Special Sensor Microwave/Imager (SSM/I) Technical Operating Report (TOR), Contract F04701-84-C-0036.

is attenuated by some loss factor in passing through the atmosphere. For microwave radiation, the important atmospheric parameters that attenuate are water vapor, oxygen, and liquid water (both in the form of cloud water and rain).

The 85 GHz channels of SSM/I were included to increase the sensitivity to atmospheric hydrometeors, particularly as a result of scattering. Absorption and emission by cloud-sized droplets is also strong at 85 GHz, which will allow for the detection of clouds.

At 85 GHz, dry snow has a low emissivity. This means that a snow surface will appear quite cold under a clear, cold atmosphere. The low emissivity of snow means that it is also a good reflector. Absorption and emission by cloud-sized droplets is also quite strong at 85 GHz. Thus, downward 85 GHz radiation from clouds over a snow-covered surface will be strongly reflected upward, adding to emission reaching the sensor directly. Comparison of cloudy and noncloudy areas over a snow background in an 85 GHz brightness temperature image will show relatively warm areas in the presence of clouds. For example, a simulated 85 GHz horizontally polarized brightness temperature of 192 K for clear conditions vs 239 K for cloudy conditions (a difference of 47 K) has been calculated for an atmosphere with mid-latitude winter temperature and humidity profiles, a surface temperature of 250 K, and a snow water content of 8 cm.[6] The cloud layer for this simulation was between 0.5 and 2 km altitude with a liquid water content of $0.15\,g/m^3$.

Comparison of cloudy and noncloudy areas over a land background in an 85 GHz brightness temperature image will also show relatively warm areas in the presence of clouds. For example, a simulated 85 GHz horizontally polarized brightness temperature of 263 K for clear conditions vs 281 K for cloudy conditions (a difference of 18 K) has been calculated for an atmosphere with mid-latitude summer temperature and humidity profiles, a surface temperature of 295 K, and soil moisture content of 12 percent.[6] The cloud layer was between 0.5 and 2 km altitude with a liquid water content of $0.15\,g/m^3$. The difference between brightness temperatures for cloudy vs clear over a land background (18 K) is less than that over a snow background (47 K). This is because land has a higher emissivity than snow. Thus, land does not reflect the 85 GHz radiation from clouds above it as well as snow.

3.2 Cloud Amount Algorithms

In the initial development of the cloud amount algorithms, it was apparent that the polarization characteristics at the 85 GHz frequency would provide much of the

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6. Savage, R.C. (Hughes Aircraft Company) (1986) Personal communication.

information. Measured microwave brightness temperatures can be described in terms of their components in two orthogonal planes; customarily, the vertical and horizontal components are measured. The vertical plane of polarization is defined by the normal to the surface and the line between the surface and the sensor. The horizontal plane is perpendicular to the vertical plane and also includes the line between the surface and the sensor. Microwave energy emitted or scattered by the atmosphere is unpolarized; that is, for a given frequency, the brightness temperature in the horizontal plane equals that in the vertical plane (within noise tolerances). On the other hand, microwave energy emitted or reflected by the surface is polarized; that is, for a given frequency, the brightness temperature in the horizontal plane is less than that in the vertical plane. (The opposite case, horizontally polarized brightness temperature greater than vertically polarized brightness temperature, is not observed in environmental remote sensing.)

In formulating the CAS and CAL algorithms, values of 85 GHz polarization (85 GHz vertically polarized brightness temperature minus 85 GHz horizontally polarized brightness temperature) for a variety of land and snow background conditions for clear and cloudy cases were calculated.[5] Some typical values are listed in Table 3. It was desired to retrieve, if possible, information on the spatial variability of clouds within the resolution of the approximately 45 km x 45 km area used by AFGWC in its RTNEPH cloud analysis. So it was decided that a single estimate of cloud amount would be based on a 3 x 3 array of adjacent dual polarized 85 GHz samples with an all-frequency (seven channel) scene at its center. *Fig-*

Table 3. 85 GHz Polarization Values (Vertically Polarized Brightness Temperature Minus Horizontally Polarized Brightness Temperature)

	Land Background	Snow Background
Clear Atmosphere:		
	6 K--dry soil	20 K--cold & shallow
		15 K--cold & deep
	15 K--wet soil	20 K--warm & shallow
		20 K--warm & deep
Cloudy Atmosphere:		
	2 K--dry soil	5 K--cold & shallow
		5 K--cold & deep
	4 K--wet soil	8 K--warm & shallow
		7 K--warm & deep

ure 3 shows a 3 x 3 array of 85 GHz footprints. The array is framed by a 39 km (along scan) x 41 km (across scan) rectangle. One 37 GHz footprint is also inside this rectangle. By summing the polarization values shown in Table 3, it is seen for a snow background that a set of nine clear 85 GHz footprints should have a total polarization value of 135 to 180 K; whereas, a set of nine cloudy 85 GHz footprints should have a total polarization value of only 45 to 72 K. Likewise, it is seen for a land background that a set of nine clear 85 GHz footprints should have a total polarization value of 54 to 135 K; whereas, a set of nine cloudy 85 GHz footprints should have a total polarization value of only 18 to 36 K. It is logical to expect that the percent cloud amount over a set of nine adjacent 85 GHz footprints is a function of the sum of the nine individual polarization values.

For land and snow-covered backgrounds, further analysis indicated that there is a significant effect of clouds on 37 GHz brightness temperatures also. For each type of background, simulated 37 GHz (vertical and horizontal polarizations) and 85 GHz (vertical and horizontal polarizations) brightness temperature values for clear and overcast conditions were calculated by Hughes Aircraft Company[6] using

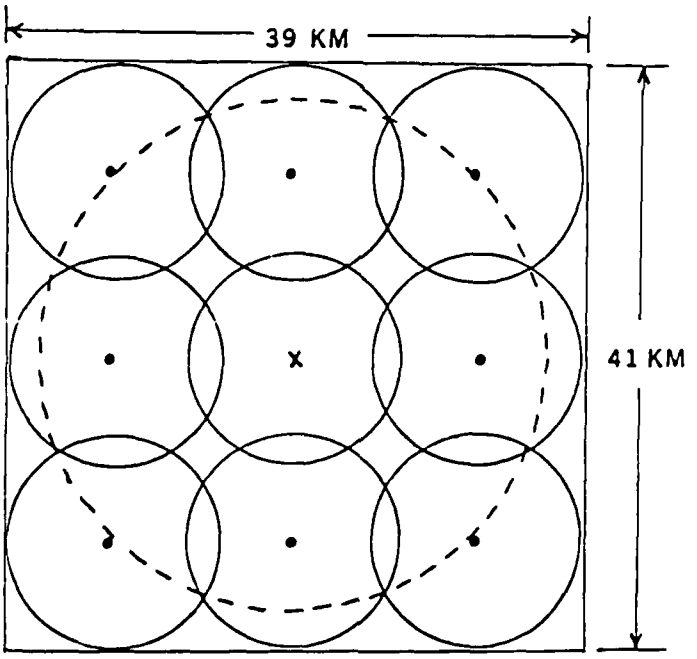

Figure 3. Area for Which a Single SSM/I Percent Cloud Amount Value Is Calculated. The rectangle contains a 3 x 3 array of 85 GHz footprints and one 37 GHz footprint. Each 85 GHz footprint is 14 km x 16 km and the 37 GHz footprint is 29 km x 36 km

the Air Force Geophysics Laboratory's (AFGL's) RADTRAN model computer code.[7] For snow backgrounds, the following conditions were set in the RADTRAN model: (1) rain-free, (2) mid-latitude winter atmospheric temperature profile, (3) mid-latitude winter atmospheric humidity profile, (4) clear or a layer of stratus/stratocumulus between 0.5 and 2 km altitude with a liquid water content of 0.15 g/m^3, (5) surface temperature varied between 230 and 270 K in increments of 5 K, and (6) snow water content varied between 4 and 20 cm in increments of 2 cm. The surface emissivity input into RADTRAN for each value of snow water content was calculated using the dry snow model of Ulaby and Stiles.[8,9] For land backgrounds, the following conditions were set in the RADTRAN model: (1) rain-free, (2) mid-latitude summer atmospheric temperature profile, (3) mid-latitude summer atmospheric humidity profile, (4) clear or a layer of stratus/stratocumulus clouds between 0.5 and 2 km altitude with a liquid water content of 0.15 g/m^3, (5) surface temperature varied between 275 and 305 K in increments of 10 K, and (6) soil moisture varied--values of 3, 5, 12, or 20 percent. The surface emissivity input into RADTRAN for each value of soil moisture was calculated using the Fresnel equations modified by a Choudhury et al.[10] correction factor of 0.6 to take into account the surface roughness effect.[9]

Hughes Aircraft Company[6] then did the following analyses. Interpolated values of the 37 and 85 GHz simulated brightness temperatures were combined, for each of the two surface types, using a random number generator (uniform distribution) to create clear fields of view (all nine 85 GHz footprints clear--0 percent cloud cover), one 85 GHz footprint overcast (any one of the nine--11.1 percent cloud cover), etc. through all nine 85 GHz footprints overcast (100 percent cloud cover). For snow backgrounds, a four-step regression produced a percent cloud amount estimation equation that accounts for 95.9 percent of the modeled variance. An error analysis of this estimation equation determined an rms error of the estimated percent cloud amount of 3.2 percent. While for land background, a four-step regression produced a percent cloud amount estimation equation that accounts

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7. Falcone, V.J., Abreu, L.W., and Shettle, E.P. (1979) Atmospheric Attenuation of Millimeter and Submillimeter Waves: Models and Computer Code, AFGL-TR-79-0253, AD A084485.
8. Ulaby, F.T., and Stiles, W.H. (1980) The active and passive microwave response to snow parameters, J. Geophys. Res. 85(C2):1037-1049.
9. Hughes Aircraft Company (1983) Special Sensor Microwave/Imager (SSM/I) Support Services Technical Operating Report (TOR), Contract F04701-82-C-0086.
10. Choudhury, B.J., Schmugge, T.J., Cheng, A., and Newton, R.W. (1979) Effect of surface roughness on the microwave emission from soils, J. Geophys. Res. 84(C9):5699.

for 77.9 percent of the modeled variance. An error analysis of this estimation equation determined an rms error of the estimated cloud amount of 7.8 percent.

The final operational version of the cloud amount over snow algorithm developed by Hughes Aircraft Company[3,11] is:

$$CAS = C_0 + C_1 *T(37V) + C_2 *T(37H)$$

$$+ C_3 *SUMT(85V) + C_4 *SUMT(85H)$$

where CAS is the percent cloud amount over snow; T(37 V) is the brightness temperature at 37 GHz--vertical polarization; T(37 H) is the brightness temperature at 37 GHz--horizontal polarization; SUMT(85 V) is the sum of the 85 GHz--vertical polarization brightness temperature at an all-frequency channel scene station and its eight surrounding 85 GHz--vertical polarization brightness temperatures; SUMT(85 H) is the sum of the 85 GHz--horizontal polarization brightness temperature at an all-frequency channel scene station and its eight surrounding 85 GHz--horizontal polarization brightness temperatures. The values of the coefficients in the above equation are: $C_0 = -189.5000$; $C_1 = -0.9710$; $C_2 = 0.7400$; $C_3 = -0.1987$; $C_4 = 0.3678$.

The final operational version of the cloud amount over land algorithm developed by Hughes Aircraft Company[3,11] is:

$$CAL = C_0 + C_1 *T(37H) + C_2 *SUMT(85V) + C_3 *SUMT(85H)$$

where CAL is the percent cloud amount over land and the other variables are the same as in the CAS equation. The values of the coefficients in the CAL equation are: $C_0 = -638.9000$; $C_1 = -1.7050$; $C_2 = -0.2868$; $C_3 = 0.7457$. Note that the vertically polarized 37 GHz brightness temperature is not used in the CAL equation. This was the final brightness temperature in the four-step CAL regression analysis, and it was found that its inclusion added only an infinitesimal improvement to the estimation accuracy.[6]

4. LIMITATIONS OF SSM/I CLOUD AMOUNT ESTIMATES

Hughes Aircraft Company developed algorithms for estimating cloud amounts from SSM/I brightness temperatures for land and snow backgrounds. No cloud

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11. Hughes Aircraft Company (1986b) Special Sensor Microwave/Imager (SSM/I) Data Requirements Document--DRD for AFGWC, Contract F04701-84-C 0036.

amount estimation algorithms for ocean or oceanic ice backgrounds were required to be developed, even though the potential over these surfaces is good. Simulated 85 GHz brightness temperatures (vertical and horizontal polarizations) over an ocean background indicate large polarization values (vertically polarized brightness temperature minus horizontally polarized brightness temperature) for clear conditions and small polarization values for cloudy conditions. For example, a cloudless, rainless atmosphere with a tropical temperature and humidity profile, and a surface temperature of 290 K has an 85 GHz polarization value of 21 K; whereas for a cloudy atmosphere (cloud liquid water content of 0.15 g/m^3) with the other conditions remaining the same, the 85 GHz polarization value is 6 K.[5] These 85 GHz polarization values over an ocean background for clear vs cloudy conditions are about the same as those given in Table 3 for snow backgrounds (15 to 20 K for clear and 5 to 8 K for cloudy). This difference in polarization values for clear vs cloudy conditions is the basis for the CAS algorithm. Hence, an SSM/I cloud amount algorithm for oceanic backgrounds is feasible.

Simulated 85 GHz vertically and horizontally polarized brightness temperatures over an oceanic ice background also indicate larger polarization values for clear conditions than for cloudy conditions. A typical 85 GHz polarization value for clear conditions over first year or multiyear ice backgrounds is 8.5 K; a typical value for cloudy conditions is 2 K.[12] These values are similar to those given in Table 3 for dry soil backgrounds (6 K for clear and 2 K for cloudy). This difference in polarization values for clear vs cloudy conditions is the basis for the CAL algorithm. Thus, an SSM/I cloud amount algorithm for oceanic ice backgrounds is also feasible.

One weakness of any microwave cloud algorithm is that ice crystal clouds (cirrus) are not discernible. Cirrus clouds are generally transparent at microwave frequencies.[5] The SSM/I cloud amount algorithms have some other limitations. SSM/I data points tagged as having a land background (based on an auxiliary fixed surface characteristic data base) are then dynamically determined to be one of nine possible land types. The types are: (1) snow over frozed ground, (2) snow over nonfrozen ground, (3) frozen soil/wet snow (indistinguishable to SSM/I), (4) glacial, (5) arable, (6) desert, (7) heavy precipitation over land, (8) flooded (lakes, ponds, swamps, etc.) and (9) vegetation. The CAS algorithm is used for types 1 and 2, and the CAL algorithm is used for types 3 through 7. No cloud amount estimates are made for land that is flooded or for land that is covered with vegetation. The potential for cloud amount estimates over flooded land from SSM/I data is good. A flooded land background is essentially the same as an

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12. Hughes Aircraft Company (1980) Special Sensor Microwave/Imager (SSM/I) Users Manual (Computer Programs)--Manual for AFGWC, Contract F04701-79-C-0061.

oceanic background. As discussed above, an SSM/I cloud amount algorithm for water backgrounds was not required to be developed by Hughes, but it is possible to devise one. The SSM/I is unable to discern clouds over land covered with vegetation. This is because vegetation contains considerable water and conceptually provides the same type of signature as a cloud. Radiatively, the vegetation resembles a very dense cloud near ground level. The amount and type of vegetation necessary for the SSM/I software to classify the surface as being covered with vegetation is presently not known. It is expected that agricultural areas where crops are fairly mature, areas of forests, and lush tropical land areas will all be classified as vegetation covered.

The inability of the CAL algorithm to calculate cloud amounts when the land is covered with dense vegetation limits its application, since cloud amount estimates over all types of land surfaces (as well as ocean and oceanic ice surfaces) are needed in AFGWC's RTNEPH worldwide automated cloud analysis model. RTNEPH's main source of data is the infrared and visible digital imagery data from the DMSP OLS sensor. Land surface temperatures are important in the infrared satellite data processor part of RTNEPH, but it is difficult to obtain accurate values. The SSM/I software contains an algorithm to calculate land surface temperatures for vegetation-covered land and all of the other land types, except for flooded land and in regions of heavy precipitation. The SSM/I-derived surface temperatures show promise of being better than those currently used in the RTNEPH, which are extrapolated from measurements made at ground stations. So, for vegetation-covered land areas and the other types of land areas, SSM/I-derived surface temperatures could be used with OLS infrared data and input into the RTNEPH to obtain cloud amount, type, and altitude values.

The accuracy of the cloud amount estimates by the SSM/I CAS and CAL algorithms is expected to be good, as is discussed in Section 3.2. However, the development of the algorithms was based entirely on simulated brightness temperatures. No previous microwave satellite sensor has measured radiation at a frequency as high as the 85 GHz channel on the SSM/I. For snow backgrounds, only one type of cloud (stratus/stratocumulus between 0.5 and 2 km altitude with a liquid water content of 0.15 g/m^3), one type of temperature profile (mid-latitude winter) and one type of humidity profile (mid-latitude winter) was used. This was also the case for the land backgrounds, where the cloud type was stratus/stratocumulus (between 0.5 and 2 km altitude with a liquid water content of 0.15 g/m^3), the temperature profile was mid-latitude summer, and the humidity profile was mid-latitude summer. The simulations should be expanded to include a variety of atmospheres, with realistic temperature and humidity profiles and clouds, to produce algorithms that would be applicable to more realistic conditions. For example, clouds often have less vertical extent and lower densities of liquid water than were assumed in

the calculations. Thinner and less dense clouds would give SSM/I observed brightness temperatures closer to those of clear conditions. Hence, it is quite possible that the accuracy of the SSM/I percent cloud amount estimates will not be as good as indicated in Section 3.2. Their true accuracy will be determined by a validation effort discussed in the next section.

5. VALIDATION PLAN

The Naval Research Laboratory is heading up a calibration/validation effort on the SSM/I instrument and on the various geophysical parameters that will be output from the SSM/I environmental parameter algorithm software. As part of this effort, AFGL is responsible for the validation of the CAS and CAL algorithms.

OLS visible and infrared data with 1.5 nmi resolutions will be interactively analyzed to obtain ground truth cloud amounts. The resolution of the OLS is considerably better than that of the SSM/I. Therefore, the ability of the OLS to resolve clouds within the SSM/I footprints is excellent. The OLS data will come from the same DMSP spacecraft that is carrying the SSM/I. This will give a near-perfect temporal match of SSM/I cloud amounts and OLS cloud amounts. It will not be a perfect temporal match because the sensors have different scan geometries. The OLS scans in a straight line perpendicular to the satellite subtrack, while the SSM/I scans aft of the satellite with a constant angle of 45° between satellite nadir and the antenna beam. For a given SSM/I scan, the OLS scan line that contains the center point of the SSM/I scan will be obtained 137 seconds prior to the SSM/I scan, while the OLS scan line that contains the endpoints of the SSM/I scan will be obtained 87 seconds prior to the SSM/I scan. The DMSP spacecraft carrying the SSM/I will be an early morning polar orbiter, which means that SSM/I and OLS data at any given Earth location will be at approximately 0605 or 1805 local time.

Two SSM/I-OLS data sets will be used in this study. Each data set will consist of all quarter orbits of 1.5 nmi OLS visible and infrared data and the corresponding SSM/I data containing North America and Greenland for a period of seven consecutive days. The first data set will be during June 1987, and the second data set will be during December 1987. Since these large data sets are for a warm and a cold season, there will be a statistically significant number of a variety of land surface backgrounds (including snow-covered backgrounds), land surface temperatures, atmospheric temperature and humidity profiles, and cloud types of differing thickness, amounts, and altitudes. Thus, the SSM/I CAL and CAS algorithms will be validated over a wide range of atmospheric and land background conditions.

AFGL's Interactive Meteorological System (AIMS)[13] will be used to analyze the OLS data to obtain percent cloud amount values for those areas where there are SSM/I-derived cloud amounts. OLS visible and infrared imagery will be displayed in scan format on AIMS. The SSM/I cloud amount rectangles (see Figure 3) will be superimposed on the OLS imagery using AIMS graphics overlay capabilities. Thus, for any given SSM/I cloud amount, the corresponding OLS visible and infrared data can be identified and interactively analyzed by a satellite meteorologist to determine ground truth cloud amount. Values of OLS-derived cloud amounts will be entered via keyboard to a ground truth cloud amount data base.

The analyses of visible and infrared OLS data discussed above will result in a data base of OLS ground truth percent cloud amount values to be used for validation of the SSM/I values. This data base will contain an OLS-derived cloud amount value corresponding to each SSM/I-derived cloud amount value from which a statistical comparison between the SSM/I and OLS percent cloud amount values will be generated.

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12. Hughes Aircraft Company (1980) Special Sensor Microwave/Imager (SSM/I) Users Manual (Computer Programs)--Manual for AFGWC, Contract F04701-79-C-0061.

13. Gustafson, G., et al. (1987) The AFGL interactive meteorogical system. Presented at the Third International Conference on Interactive Information and Processing Systems for Meteorology, Oceanography, and Hydrology, New Orleans, La., January 12-16, 1987. American Meteorological Society, Boston, Mass.

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